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Test of Horizontal Field Measurements Using Two-Axis Hall Probes at the APS Magnetic Measurement Facility

I. Vasserman
Advanced Photon Source
Argonne National Laboratory
Argonne, IL 60439

1. Introduction

The free-electron laser (FEL) project at the Advanced Photon Source (APS) will use a 400-MeV particle beam from the APS linac with RMS beam transverse size of 100 µm and requires very high performance of the insertion devices in order to achieve high intensity radiation. Averaged over period, the trajectory must deviate from the ideal on-axis trajectory by not more than 10% of the RMS beam size. Meaning that the second field integral should be straight within ±1300 G-cm^2 over the length of the device for both horizontal and vertical directions for the 400-MeV particle beam. Under such conditions, special attention should be given to the measurement technique and tuning.

Two types of probes were tested to examine the possibility to measure small horizontal field in presence of strong (up to 1 T) vertical magnetic field without the distortion associated with planar Hall probe effect. They are a two-axis Sentron analog Hall transducer and a two-axis Bell probe. The Sentron probe is a new type of Hall probe, a so-called vertical Hall device, which is sensitive to the magnetic field parallel to the chip plane [1]. The Bell probe is a conventional-type probe sensitive to the magnetic field perpendicular to the chip plane. A flipping coil and an 81-mm-long moving coil were used to make the reference measurements. Insertion device Undulator A #3 was used for these measurements with a gap of 11 mm and a peak field of about 0.85 T.

2. Angular Orientation Dependence

The well-known planar Hall effect is responsible for distortion of horizontal field measurements in the presence of a strong vertical field. This effect has been studied in detail for regular Hall probes [2, 3,], but we did not see any reports on this subject for the new types of Hall probe. To obtain correct results for the horizontal field, very precise alignment of the axial probe orientation should be done in this case. Dependence of the first horizontal field integral on the angular orientation of the axial probe is shown in Fig. 1 for a Bell two-axis probe and a Sentron Hall transducer. The sensitivity to orientation is very high, 63 G-cm/mrad, for the Bell probe. The Sentron probe is almost insensitive (ten times smaller) to such distortion.

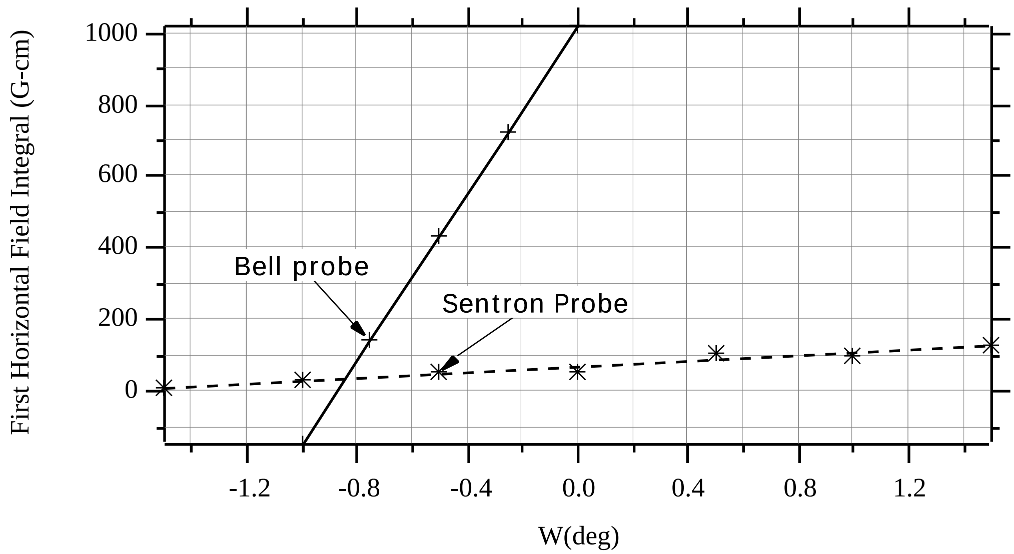

Fig. 1 Sensitivity of Bell and Sentron Hall probes to angular positioning

3. Dependence on Vertical Position

Tests were performed to investigate this subject due to the strong dependence of magnetic field distribution on the vertical position at undulator-type devices. The results are shown in Fig. 2 for both the Sentron and Bell probes. The vertical position dependence of the Sentron probe is very similar to the angular dependence of the Bell probe; the same type of strong linear dependence is present. The dependence of the Bell probe shows a more complicated character; it is possible to find a region where such dependence is quite weak. From Maxwell's equations, we have $\partial B_y/\partial x - \partial B_x/\partial y = 0$. The results of measurements of the first vertical field integral dependence on X, $\partial J_y/\partial x$, made by Hall probe and flipping coil do not show such strong dependence as we have for $\partial J_x/\partial y$, measured by Hall probes. The results of measurements of $\partial J_x/\partial y$ made by flipping coil agree with Maxwell's equation, which means that measurements of $\partial J_x/\partial y$ made by an axial Hall probe are not real and have some induced error.

The question of interest is: what is the reason of such Hall probe dependence? A possible explanation could be associated with the existence of a longitudinal magnetic field out of the device center line. This field has different signs for the y>0 and y<0 locations and creates the components responsible for the planar Hall effect in the plane of the Hall plate.

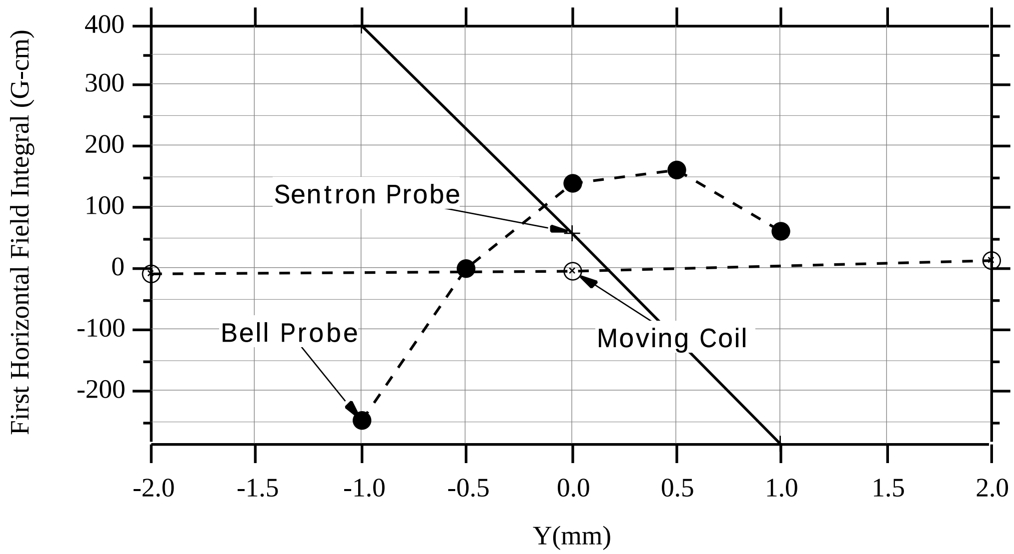

Fig. 2 Sensitivity of Bell and Sentron Hall probes to vertical position

4. Final Alignment of Probes

The next set of measurements was performed to find the conditions under which reliable and correct results could be obtained. This task looks to be simpler in the case of Sentron probe due to its insensitivity to angular orientation. All we need is to locate the center line of the probe. Comparison with flipping coil and moving coil integral measurements allows confirmation of the final alignment configuration.
The procedure of alignment was as follows.

4.1 Sentron Probe

Scans for different vertical positions were performed to find the location of the center line where results of the first horizontal field integral should be in agreement with the flipping coil and/or stretch wire coil and/or moving coil measurements. Alignment of the Hall plate in the probe is rather precise, so it is enough to locate the center of the probe on the axis of the device. The second field integral does agree in this case as well. No special attention should be paid to angular positioning of the probe.

4.2 Bell Probe

Vertical alignment is needed to bring the probe to the location where field dependence on probe position is small, taking into account that positioning of the Hall plates inside the probe is not precise. The second step is angular positioning of the probe. An accuracy of 1 mrad may be needed to achieve good agreement with reference measurements.

4.3 Results of the Measurements

The alignment of both types of Hall probes was made to match the results of the first horizontal field integral obtained from reference integral measurements. Results of the horizontal field measurements averaged over the undulator period are shown in Fig. 3 for both probes. Calculated from these measurements, trajectories are shown in Fig. 4. The longitudinal location of poles from the upper and lower jaws should be precise enough to avoid deflection of the main field from the vertical direction, resulting in a planar Hall effect for the Bell probe. Otherwise it may be impossible to find the proper position of the probe. Results of the measurements, shown in Fig. 4 (for the particle trajectory), prove this statement. Whereas the final trajectory displacement calculated from the field data of the Sentron probe, located on center line of device, is in good agreement with reference measurements, the Bell probe results are different by about 100 μ. It is possible to improve the agreement between the Bell probe and the Sentron probe, if we match not the first field integrals but the trajectory itself (see Fig. 4), however, the disagreement is still too large. The most plausible explanation is that alignment of the poles in the longitudinal direction is not good enough for such measurements.

It is worth mentioning that the accuracy of the position of the center line of different poles is important, especially for the Sentron probe, to get correct results. This is quite clear from the results of the measurements shown in Fig. 2.

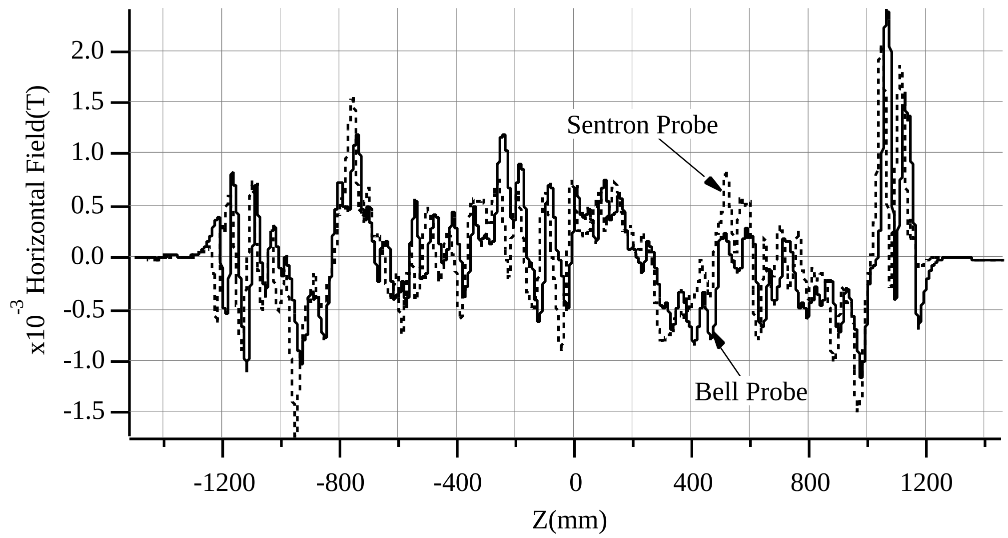

Fig. 3 Comparison of horizontal magnetic field measurements using different probes, averaged over undulator period

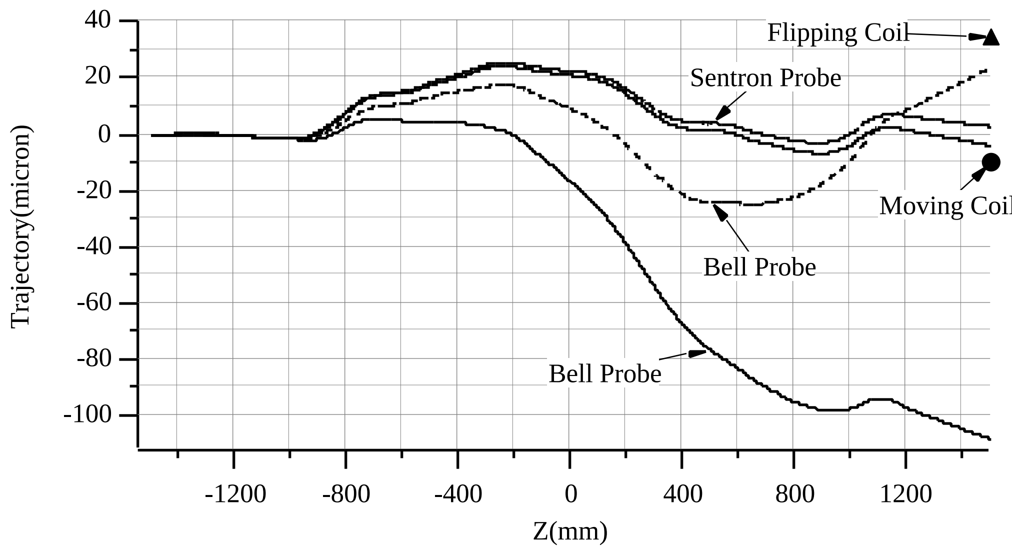

Fig. 4 Comparison of horizontal trajectory measurements using different probes

References

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2. D. Swoboda, IEEE Trans. Magn. MAG-17, 2125 (1981)
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